Analysis of Natural Draught Hyperbolic Cooling Towers by Finite Element Method Using Equivalent Plate Concept

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Abstract:

This paper leads to software package utilized towards a practical application by considering problem of natural draught hyperbolic cooling towers. The main interest is to demonstrate that the column supports to the tower could be replaced by equivalent shell elements so that the software developed could easily be utilized. For demonstrating this, a single case of the tower with alternative 'I' and 'V' supports is taken up. It is demonstrated that the behaviour in respect of equivalent plates are identical to the behaviour where the actual column supports are considered. For this the wind load over the structure is applied.

Keywords:
natural draught hyperbolic cooling tower, finite element analysis, equivalent plate thickness, radial deformation.

1. Introduction

The algorithms utilized in the analyses of shell [1] are employed towards demonstration of their applicability to an important practical problem. For this, the *Natural Draught Hyperbolic Cooling Tower* is considered.
The towers in practice are supported either by I column system or V column system. In reference [2], a tower of 175m height has been considered with this alternative supporting system. It is obvious that by taking up the investigation of these towers an additional benefit occurs in the manner of comparison of the relative effectivity of these alternative support systems. In view of this, the data pertaining to these towers has been used herein for investigations.

2. Description of Towers

The geometry configuration of cooling tower shell is defined by [3],

$$r = \Delta r + a\left[\sqrt{\left\{1 + \left[\frac{(z-125)^2}{b^2}\right]\right\}}\right]$$

Where, r is radius of tower shell at a height 'z' (m). The parameters a, b, Δr are, as per table 1.

Table 1 Basic Data for Cooling Towers

Height (z)	9.17m - 125m	125m – 175m
A	51.9644	0.2578
B	113.9896	8.0293
Δr	-15.3644	36.3422

Accordingly, the profiles of the towers are as shown in fig. 1. All the Elevational details i.e. height of tower, indicated in the following fig. 1, are in meters.

Material properties of concrete considered are:
$E = 3.4 \times 10^7$ kN / m², $\nu = 0.167$, $\gamma_{conc} = 23$ kN / m³

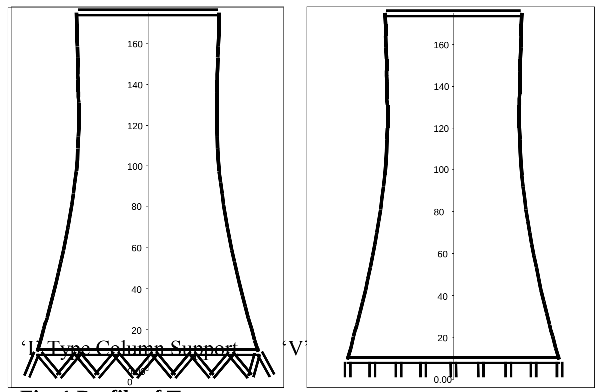


Fig. 1 Profile of Tower

3. Finite Element Idealizations

The finite element idealization for both the towers is developed by employing both 4 noded plate elements [4]. In this, 32 elements in hoop direction and 30 elements in meridional direction are provided. The height is 175m and the thickness of the shell changes from 105cms at the lintel level through 20cms at the top of tower. In the meridional direction, the model has the mean radii and the shell thicknesses at various elevations as shown in table 2. (All dimensions are in 'm')

Table 2 Elevational Mean Radius and Thickness Details

Ht.	Mean R	Thickness	Ht.	Mean R	Thickness
0.000	61.755	0.9 sq c/s	86.566	39.476	0.510
2.293	60.986	0.9 sq c/s	92.095	38.723	0.471
4.586	60.224	0.9 sq c/s	97.623	38.079	0.433
6.879	59.468	0.9 sq c/s	103.152	37.547	0.394
9.170	58.720	1.050	108.680	37.131	0.356
14.698	56.945	1.011	114.209	36.833	0.317
20.225	55.217	0.973	119.737	36.656	0.278
25.753	53.536	0.934	125.266	36.600	0.240
31.281	51.908	0.896	130.794	36.660	0.231
36.810	50.337	0.857	136.323	36.787	0.227

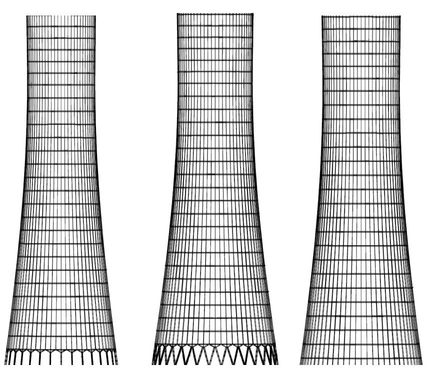
42.338	48.826	0.819	141.851	36.941	0.222
47.867	47.380	0.780	147.380	37.105	0.218
53.395	46.003	0.741	152.908	37.274	0.213
58.924	44.700	0.703	158.437	37.446	0.209
64.452	43.477	0.664	163.965	37.619	0.204
69.981	42.338	0.626	169.494	37.793	0.201
75.509	41.288	0.587	175.001	37.968	0.200
81.038	40.332	0.548			

There are 16 column supports supporting the alternative nodes at the base of the tower. The c/s of the columns is 90cms x 90cms. The idealization of columns is carried through 4 segments of two noded line elements. These details for 'I' type and 'V' type supports are presented in fig. 2. For both the models the base nodes of columns i.e. from node numbers 1 to 16 are kept fixed for all the six degrees of freedom (u, v, w, θ_x, θ_y, θ_z) and the models the structural system has been analysed for its self weight and also along with that it has been analysed for the effect of wind load [5], [6]. Its intensity has been calculated by using IS 875-III [7], which is especially for the *Code of Practice for Design Loads (Wind Loads).*

4. Linear Elastic Response - Concept of Equivalent Plate Thickness

As pointed out above the linear elastic response for the towers is derived in respect of application of the self weight and the wind load. In view of the fact that the soft-wares employed for the cylindrical shells deal exclusively with plate elements [8], a concept is developed wherein the column supports have been transformed into equivalent shell elements, so as to treat the complete tower system as a shell structure.

The equivalent plate thicknesses for the column supports are based upon a consideration that the vertical deflection at the top of the tower remains same as the once due to column support wherein only the influence of the self weight is considered.



Equivalent Plate Profile

Fig. 2 Idealization Schemes showing Column and Equivalent Plate Details for 'I' and 'V' Type Column Supports

As the complete development of the software for analysis of various types of elements is employing exclusively the plate elements therefore it was considered more practical to transform the column supports in the towers for equivalent plates. For this the influence of the self weight was considered by analysing the tower structures with columns and plate combinations. The vertical displacement at the top was determined through this analysis. For deriving the equivalent plate thickness 4 noded plates were considered with the idealization now taking the format as shown in fig. 2.

With this kind of idealizations numbers of trials are taken to arrive at the plate thickness which would produce the same vertical deflection as was found out for the column plate systems. In this manner the equivalent thickness't' for the 'I' column supports was derived equal to 0.040m and for 'V' column support it was derived equal to 0.037m.

It may be noted that as far as different types of supports are concerned the equivalent thicknesses are quite close to each other. To ascertain the validity of this kind of alternative formulation for carrying out the further kind of analysis the influence of the wind loads is examined for both the column plate system and the equivalent plate system. The results for the sway suffered by the systems are indicated in fig. 3 and table 3.

In the graph presented below y axis indicates Elevational height in meters, while x axis indicates the displacement due to wind load in meters.

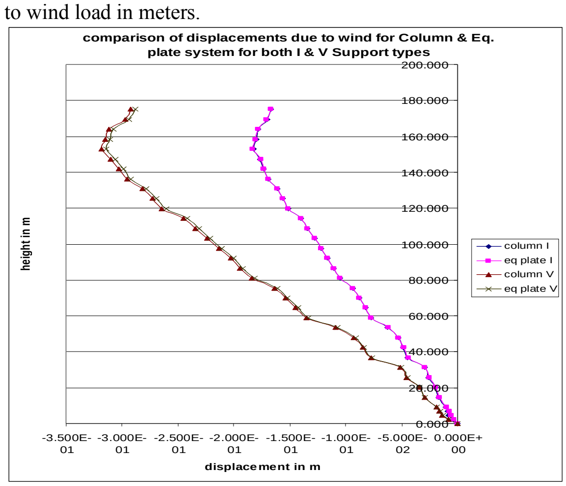


Fig. 3 Comparison of Displacements due to Wind

		I Supports	V Supports
Displacement in m due to wind load at extreme top level	Column	0.167	0.292
	Plate	0.167	0.290

Table 3 Sway Details by Wind Load

It is possible to conclude that;
The deflected profile is almost identical in case of equivalent structure as compared to the original structure.

1. The present investigation is planned to compare relative behaviour of 'I' supports and V' supports. The details in fig. 3 reveal that the 'V' support system is more flexible compared to 'I' support system.
2. With a view to achieve the thorough validation of the concept of the equivalent plate thickness, the radial deflections at the throat section were also compared as shown in fig. 4. Once more the conclusions in (1) and (2) above are also found to be valid for the throat section of the tower.

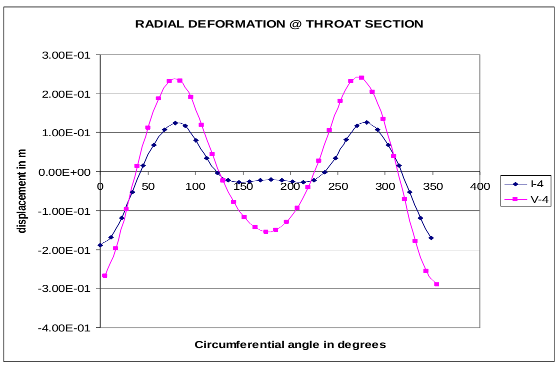


Fig. 4 Radial Deformation @ Throat due to Wind

5. Elasto-Plastic Analysis

For both the towers the elasto-plastic analysis is performed by adopting the equivalent plate idealizations developed above. For this the applied load is wind load along with the load due to self weight. As the structural systems are huge it is considered impractical to present graphically the development of the phenomenon of plastic flow [9].

i) For 'I' type support system

The zone of plasticity starts with throat region. It further progresses in the downward direction and finally it flows in both upward and downward direction till the collapse load is reached. In fig. 5 percentage details are given.

ii) For 'V' type support system

Similar response is also observed for this type of system.
Table 4 indicates the collapse loads i.e. wind load multiplier factor for both the types of towers by 4 noded and 9 noded plate elements.

Table 4 Collapse Loads (Wind Load Multiplier)

		I support	V support
Wind load multiplier factor	*4 noded Flat plate element*	7	5
	9 noded Flat plate element	7.5	7.5

However, some salient features drawn from the actual details are presented herein in fig. 5.

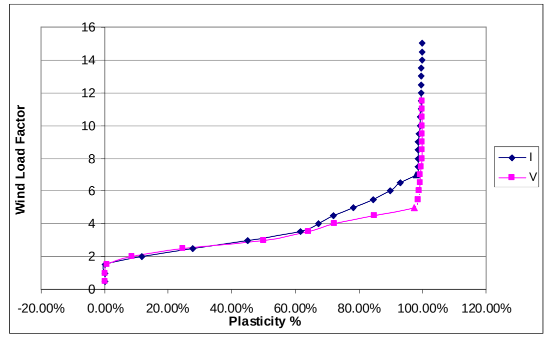


Fig. 5 Percentage Flow of Plasticity in Towers due to Wind Load by 4 noded Plate Element

The results in fig. 5 reveals that between the 'I' and 'V' supports there is not much difference between the plasticity development however for the 'V' support the lesser load is required for the flow of plasticity in the region of 60% degree of plasticity and full collapse. In fact, this is expected because it has already been observed that the 'V' support system is more flexible.
The basic phenomenon of development of the plastic flow remains similar to one observed with 4 noded plate formulations. The percentage development characteristics are as shown in fig. 6. However now no significant difference is observed between the 'I' support and 'V' support.

6. Influence of Reinforcement

In the manner presented in previous paper [10] the incorporation of the reinforcement is achieved through equivalent steel plate pasted on the idealized system. Thus while maintaining the number of nodes same the number of elements get doubled. The thickness of the steel reinforcement is derived by assuming 2% of the average thickness of the tower, which comes about to be 10mm. For this once more the elasto-plastic analysis is conducted and the results are as shown in fig. 6.

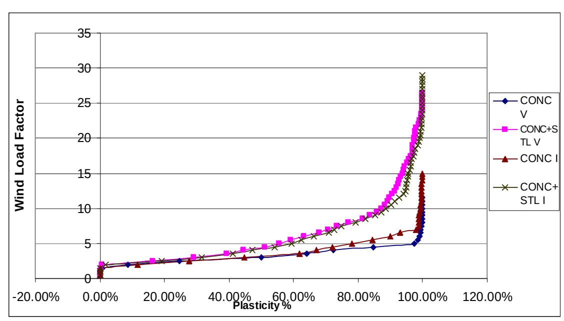


Fig. 6 Percentage Plasticity Flow in Towers due to Wind Load by 4 noded Element with and without Reinforcement

From table 5 and fig. 6, it may be concluded that both 'I' support and 'V' supports have identical response in case of the RCC formation. It means that the small difference which was earlier observed for the concrete sections has also now vanished. This may be termed as positive influence of incorporation of the steel reinforcement in the concrete components.

Self Weight + Wind Load Multiplier	'I' Support		'V' Support	
	Concrete	With Steel	Concrete	With Steel
	7	9.5	5	8.5

On comparison of the response of RCC component and concrete components as expected RCC components have higher level of collapse load.

7. Summary and Conclusions

1) The main aim of the analysis work on the cooling tower has two folds:

a) To compare the structural behaviour of the tower with different foundation supports such as 'I' support and 'V' support;

b) To provide a rational basis for transforming each of these support types into equivalent shell surfaces, so that various softwares employed in the basic investigation of the shells could be utilized.

2) From fig. 3, it is observed that the equivalent shells provide identical deflected profiles for the application of the wind loads, as those due to actual supports.

3) The 'V' supports create relatively more flexible structure compared to the one having 'I' supports. From fig. 3 and table 3, this is indicated by virtue of development of more sway in case of 'V' support with respect to 'I' support when the influence of the wind load is considered.

4) From table 3, it is noticed that the 'V' supports give 73.6% more sway than 'I' supports in the case of column supports as well as equivalent plate system due to application of wind load.

5) The progress of the development of the plastic zones has shown for both kinds of support systems initiation at the throat level and subsequently first progressing towards the downward direction over the height of the towers and then it progresses towards both downward as well as upward direction also.

6) It is observed from fig. 5 that the collapse load pattern derived for 'I' support systems and 'V' support systems are farley similar.

7)From table 4, it is observed that the collapse load in case of 'I' support system is having 40% higher value than in case of 'V' type support systems.

8) From table 5, it is clearly seen that the structure with the provision of reinforcement i.e. steel plate, can sustain almost 35 to 50% more collapse load than that of plain concrete.

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